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Phytoextraction Applications for Remediation of Lead Contaminated Soils

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Company Highlights

- Edenspace is a systems technology company that uses living plants in innovative products and services to restore and enrich our surroundings.
- Founded in 1998, Edenspace is headquartered in Dulles, Virginia, with 14,000 ft^2 of new office, laboratory, and growth chamber space.
- Edenspace acquired Phytotech's phytoremediation business in June 1999, thereby becoming the world leader in the use of plants to extract minerals from soil and water, including lead, uranium, arsenic, and radionuclides.
- Successful completion of phytoextraction demonstrations and commercial projects.
- As a result of its own research and agreements with Rutgers University, University of Florida, and the University of Washington, Edenspace now owns or has exclusive license to 12 patents in the areas of phytoremediation, phytoextraction, and rhizofiltration.

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Technology Applications

- **Industrial Soil Lead** *In-Situ* RCRA Corrective Action, combines phytoextraction with phytostabilization.
- **Residential Soil Lead** Residential phytoextraction using turfgrass.
- **Firing Range Lead** *Ex-situ* phytoextraction of small arms firing range soils.
- **Phytoextraction in Arid Environments** DOD-sponsored (through New Mexico State University) program for the development of phytoextraction in arid regions
- **Phytoextraction of Arsenic** *In situ* phytoextraction of arsenic contaminated soils using ferns.
- **Phytofiltration** Arsenic removal from wastewater and drinking water.
- **Phytoextraction of Strategic Metals** Tungsten and molybdenum biomining.

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Phytoremediation's Place in the Remediation Tool Box

- Phytoremediation is a tool, but as with any tool, it works best when used properly. When used improperly the results are unpredictable.
- Knowing when to use it (and when not to) is as important as knowing how to do it.

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Process Overview

- **Site applicability/treatability analysis**
  - **Soil chemical and physical analysis**
  - **Phytometric parameters**
    - Metal solubility/chemical fractionation
    - Extractability
  - **Soil suitability for plant growth and metal uptake**
- **Sampling plan - determine baseline soil concentrations**
- **Develop agronomic/phytometric procedures**

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Phytoremediation of Heavy Metal Contaminated Soils

- **Heavy metals are relatively insoluble and unavailable for plant uptake**
  - Pb activity in most agricultural soils is approximately $10^{-8.5}$ M (Lindsay, 1979) or 0.5 ppb
- **Plant available metals have already been removed or converted to insoluble forms**
- **Remediation standards are based on total metal concentration in the soil rather than bioavailability**
- **Very few suitable natural hyperaccumulating plants have been identified. No known natural hyperaccumulators for lead exist.**

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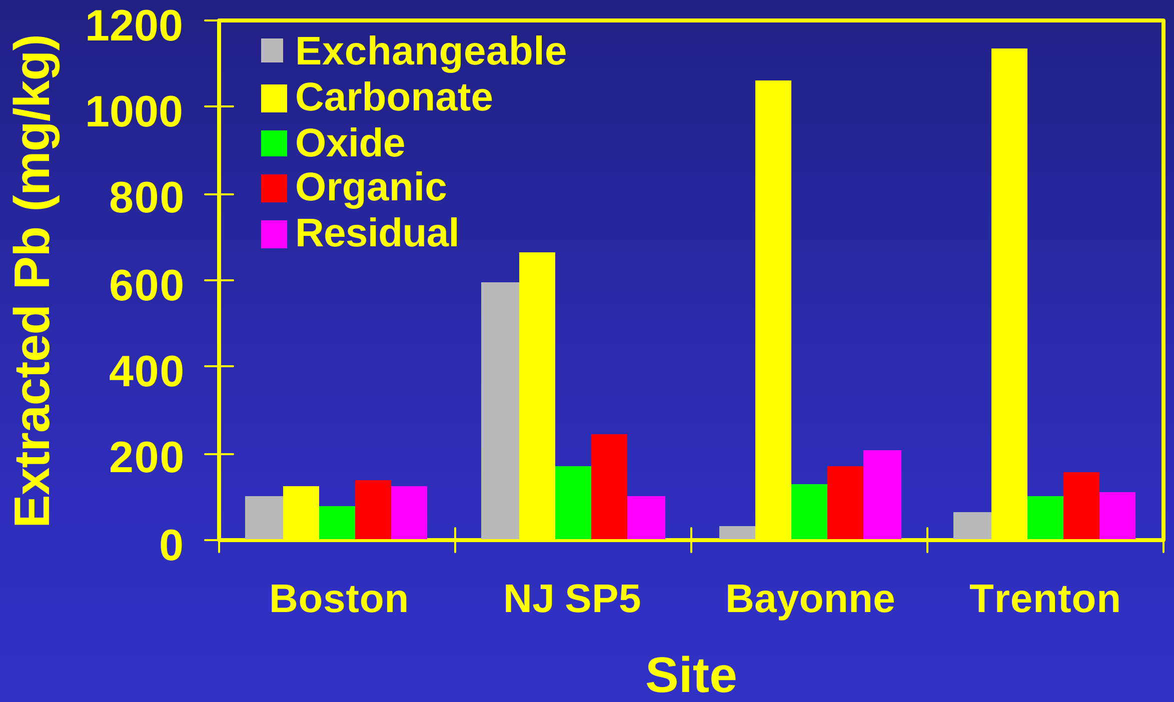
Lead Fractionation in Soils



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Phytoextraction Decision Criteria

Contaminant Suitability
- Bioavailability
- Concentration
- Depth of contamination
- Cleanup goal
- Time frame

Site Conditions
- Potential land use
- Soil characteristics
- Hydrology
- Existing vegetation
- Climate

Technology Approach

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Technology Options

- *In situ* vs. *ex situ* treatment
- Integrate phytoextraction with compatible technologies
  - Soil washing (physical treatment)
  - Stabilization
  - Excavation and disposal
  - Electrokinetics
- Phytoextraction techniques
  - Induced uptake
  - Natural accumulation or enhanced natural accumulation
  - Enhanced passive accumulation

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Induced Uptake

- Rapid, short-term uptake through the use of soil and foliar amendments.
- The crop is grown to a specific growth stage and then treated to induce metal accumulation in the harvestable plant tissues.
- Particularly suited for metals with low plant availability (lead and uranium).
- Minimizes exposure to high contaminant concentrations in plant biomass.
- Requires the ability to rapidly increase plant availability of contaminant.

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Increasing Metal Solubility/Availability

- **Acidification - pH adjustment**
  - Increases solubility of free metal
  - Difficult to overcome soil buffering capacity
  - Build-up of high salt concentrations
- **Ion exchange**
  - High concentrations required for effective displacement of sorbed ions
  - Competitive interactions for plant uptake, i.e., As & PO_4, Cs & K
- **Chelation/complexation**
  - Soil extractants and micronutrient fertilizer sources
  - Increase total soluble metal with a decrease in free metal
  - Minimal effects on anions and monovalent cations
  - Potential phytotoxic effects
  - Risk of leaching and increased metal mobility

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Natural Accumulation

- Utilizes the natural ability of select plants to accumulate certain metals.
- Plant and contaminant specific, very few suitable natural hyperaccumulating plant species have been identified.
- Uptake occurs gradually during the plants life cycle.
- No amendments required.
- Contaminant must be plant available.

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Enhanced Passive Accumulation/Stabilization

- Long term, gradual contaminant uptake or removal.
- Only moderately elevated levels of contaminant are accumulated in the biomass.
- Minimal soil and foliar amendments.
- Biomass is non-hazardous.
- Suitable for long term maintenance or passive phytoremediation when no specific time frame or remediation goal is established (residential lead contaminated soils).

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Overcoming Challenges

- **Recalcitrant metals, particulate contamination**
  - Soil washing - particle size separation to remove particulates and fragments followed by phytoextraction to remove remaining plant available metals
  - Phytostabilization to minimize runoff and leaching of contaminants
- **Contaminants below the root zone**
  - Excavation followed by *ex situ* phytoremediation treatment
- **Unfavorably high metal concentrations**
  - Identification and segregation of concentration zones followed by phytoextraction of suitable areas combined with excavation of less favorable areas
- **Unfavorable groundwater or undesirable leaching conditions**
  - *Ex situ* treatment
  - Liner and water management, root growth metrics

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Case Study - Phytoextraction/Phytostabilization

Site Conditions

- Surface soil lead
- Groundwater concerns
- Address leachable lead as well as total lead concentrations
- On-going site use and activities

Approach

- Identify soil areas exceeding 1000 mg/kg total lead
  - Use phytoextraction to decrease total soil lead followed by phytostabilization to remove soluble and leachable (SPLP) lead
- Remaining areas receive phytostabilization to remove bioavailable lead

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Phytostabilization Results

- Areas exceeding total lead concentration goals were reduced.
- Average lead concentrations from all crops exceeded 1000 mg/kg.
- SPLP leachable lead decreased from an average of 0.85 mg/l to 0.08 mg/l.
- No elevated levels of lead detected in shallow groundwater, during the three-year project

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Ex Situ Phytoextraction - Fort Dix, New Jersey

Site Conditions

- Initial lead concentrations ranging from 160 to 10,000 mg/kg with an average of 516 mg/kg.
- Low soil fertility and water holding capacity (predominantly sand)
- Lead contamination consists of bullets, bullet fragments and ionic lead forms.

Approach

- Excavate and process soil to remove lead fragments.
- 3,500 tons of soil placed into 12-inch deep constructed phytocell for phytoextraction to remove ionic lead and achieve total lead goal (400 mg/kg).
- Drainage water was recirculated through the irrigation system.

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Fort Dix - Summary of Results

- The average lead concentration decreased from 516 ± 35 mg/kg (mean ±80% confidence interval) to 290 ± 67 mg/kg (mean ±80% confidence interval).
- Final TCLP concentrations of the treated soil were less than 1 mg/L.
- 110,000 gallons of recirculated drainage water remained at the end of the demonstration containing lead representing a soil lead concentration of approximately 30 mg/kg.

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Soil Amendments - Friend or Foe

- Soil applied chelating agents are critical to the successful application of phytoextraction for lead contaminated soils.
- There is an increased risk of metal mobility when compounds such as EDTA are applied to the soil. However, we have only been able to detect leaching in ex situ applications using recirculated drainage water.
- In situ applications have not detected any increase in downward lead mobility.
- Solubilizing compounds (i.e., citrate) that readily degrade are proving to be effective alternatives.

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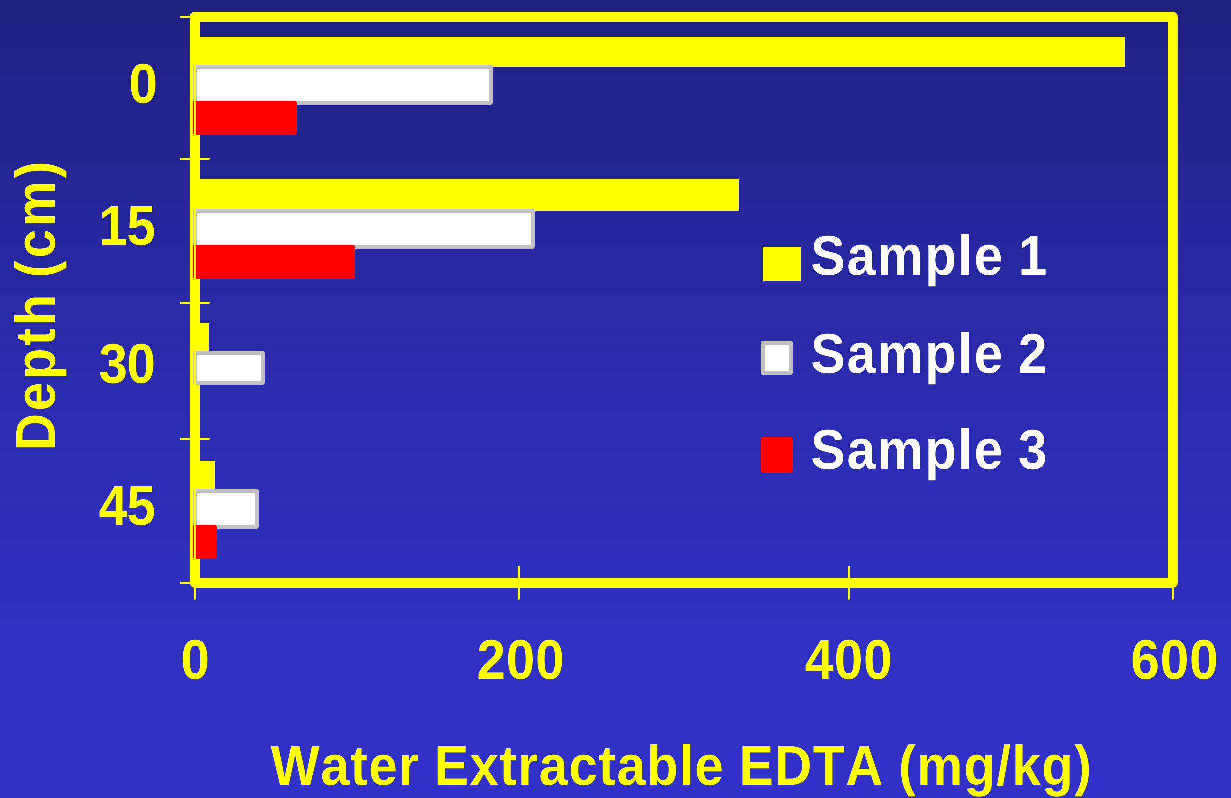
EDTA Distribution in the Soil with Depth

Six Months After Application of 3000 mg/kg EDTA



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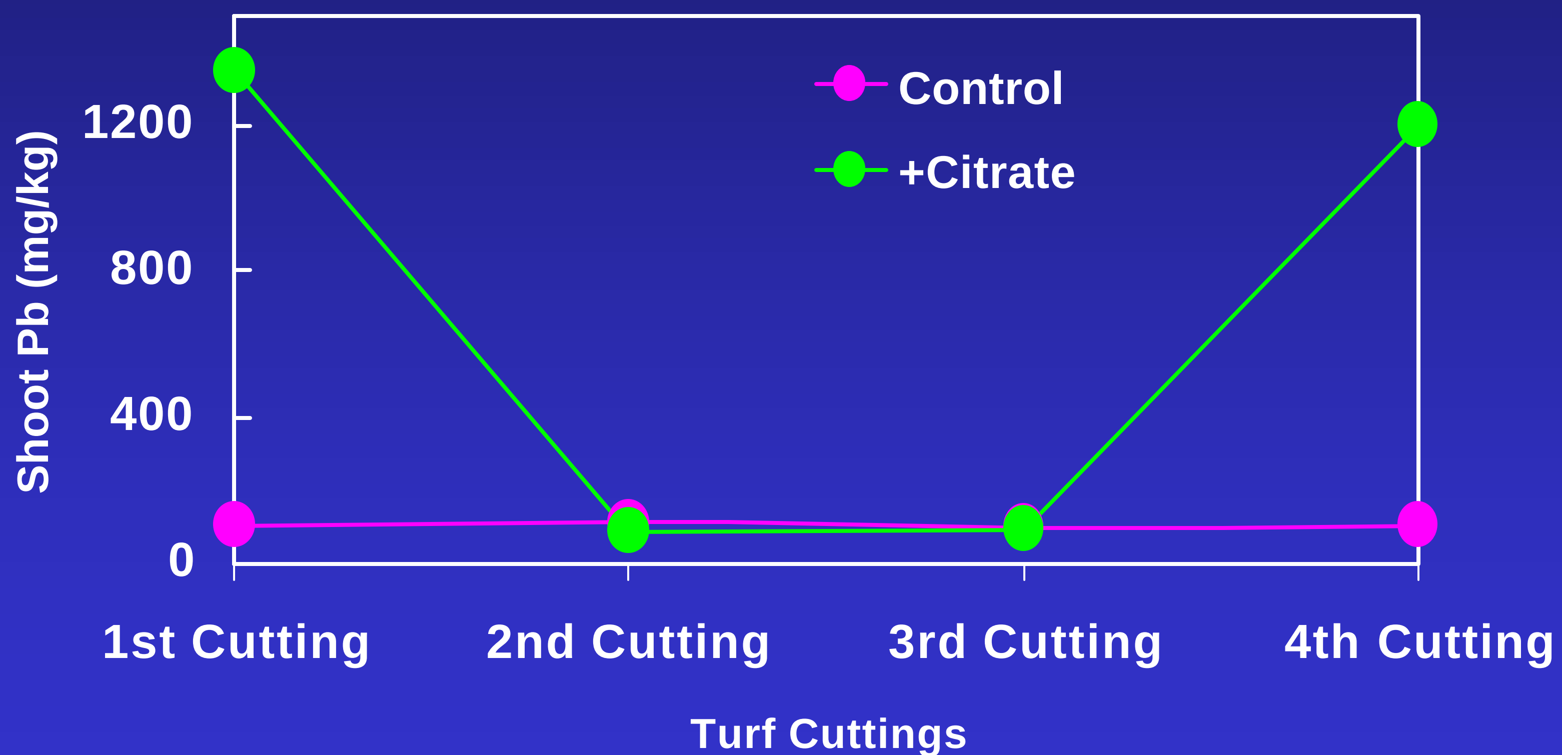
Control of Lead Uptake Using Citrate with Turfgrass



(Citrate applied before 1st and 4th Cuttings)

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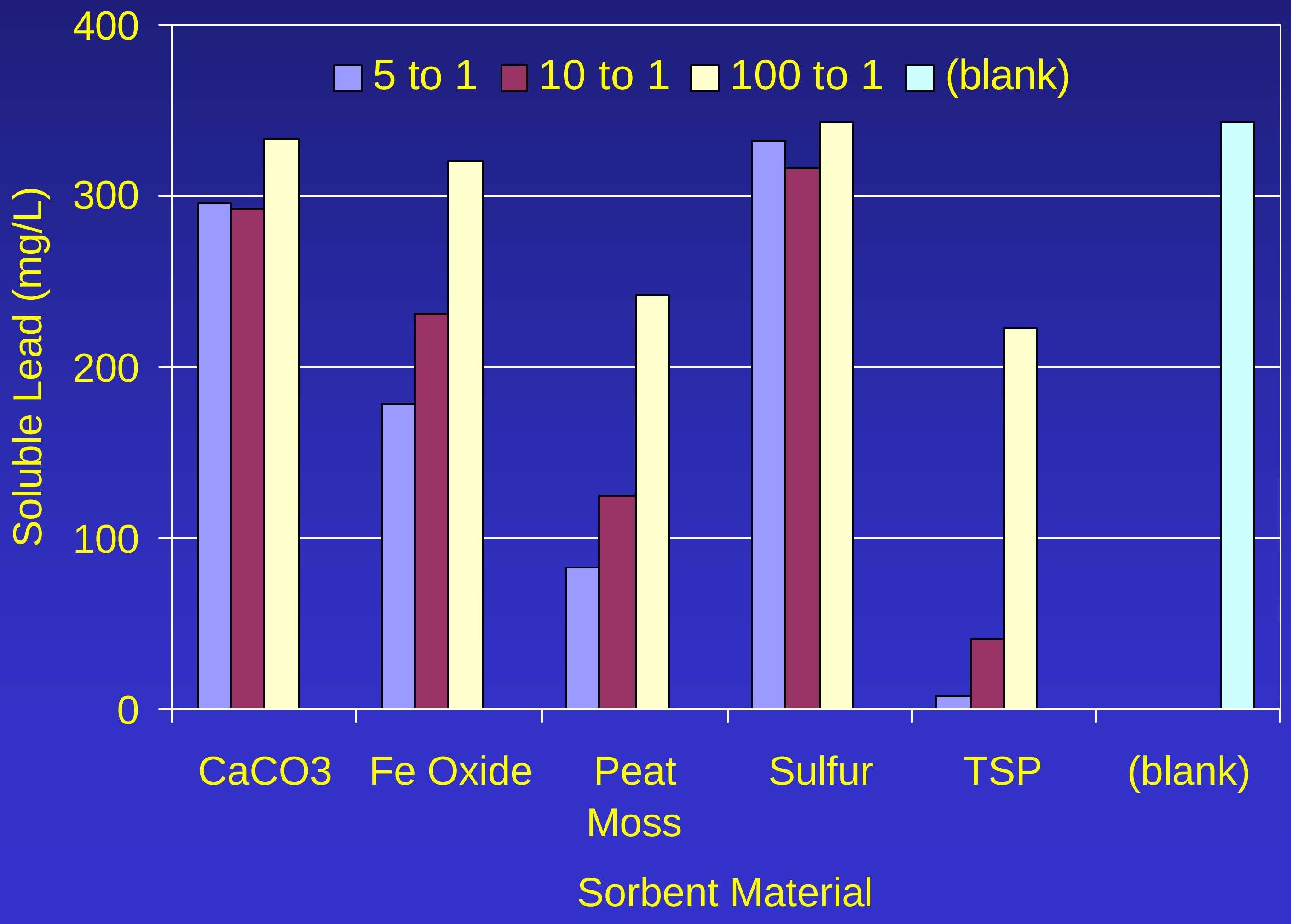
Removal of Chelated Lead from Water



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Summary

- Phytoextraction has been demonstrated as an effective means to address lead contaminated soils.
- The use of soil amendments to enhance metal solubility and uptake should be done only after proper site characterization has occurred.
- Additional research has resulted in the development of techniques to reduce and minimize the leaching risk.